ATIP Report: Cryospheric Research in China

ATIP/China

ABSTRACT: The last decade has seen increasing interest in cryospheric processes in the Earth's cold, high-elevation regions, as the cryosphere is a very sensitive indicator of climate change in the context of global warming. It is also fundamental to the maintenance of oasis economies in arid areas and ecosystem stability in cold regions. China has the largest cryospheric area among countries at mid- and low- latitudes. The effects of cryospheric change on climate, environment, water resources, and ecology in China are very notable, which makes this topic area highly significant to national strategic development. This report presents the current situation of cryospheric research in China, primarily including the relevant key national research and development (R&D) programs, domestic leading research groups/organizations, and a short review of recent research advancements in the field, as well as a discussion of research trends.

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14. ABSTRACT

The last decade has seen increasing interest in cryospheric processes in the Earth???s cold, high-elevation regions, as the cryosphere is a very sensitive indicator of climate change in the context of global warming. It is also fundamental to the maintenance of oasis economies in arid areas and ecosystem stability in cold regions. China has the largest cryospheric area among countries at mid- and low- latitudes. The effects of cryospheric change on climate environment, water resources, and ecology in China are very notable, which makes this topic area highly significant to national strategic development. This report presents the current situation of cryospheric research in China, primarily including the relevant key national research and development (R&D) programs, domestic leading research groups/organizations, and a short review of recent research advancements in the field, as well as a discussion of research trends.

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EXECUTIVE SUMMARY

- In China, most of the key national R&D programs involve cryospheric research, such as the National Basic Research Program (973 Program) and the National Fundamental Investigation Projects (NFIP Program) by the Ministry of Science and Technology (MOST) as well as major programs by the National Natural Science Foundation of China (NSFC) and the Chinese Academy of Sciences (CAS), etc. As a priority field to be funded due to its importance to national strategy, sustained R&D funding from the Chinese government has been invested for decades, playing an important role in the promotion of cryospheric research in China.
- Chinese researchers have participated or are joining in numerous international cooperation research projects that are authoritative and influential in the field. International peers have been making positive comments regarding China's role in international research cooperation and the country's important contributions to cryospheric studies in recent years.
- Many universities and research institutes involved in earth and environmental sciences are presently conducting cryospheric research. Among them, most of the important academic achievements come from those research organizations located in the cold regions of China. CAS institutes represented by the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) and the Institute of Tibetan Plateau Research (ITP) are the leading players nationwide, with strong R&D capability, high-end talents, adequate R&D funds, and a relatively long research history in the field.
- As one of the early countries in the world conducting relevant research, China has made great progress in research on cryospheric change and its impact through continuous investigation of glacier inventories, frozen ground observations, paleo-climate analyses of ice cores, process studies, and the modeling of cryospheric/atmospheric interactions, etc. However, the current research basis of the field still remains relatively weak, and the examination of possible strategies for adapting to the impacts of cryospheric change is still in its infancy in China and needs to be strengthened in the future.

IMPACT & ASSESSMENT

In recent decades, scientists from different countries have used cryospheric science to understand the causes and consequences of global climatic and environmental changes, both natural and anthropogenic. Among these countries, China is always an active player and key contributor to the advancement of this field. ATIP believes that understanding the current situation of cryospheric research in China is necessary, because the future of cryospheric research requires more international cooperation and data sharing with China as the country with the third-largest cryosphere in the world.

1. INTRODUCTION

Along with atmosphere, hydrosphere, lithosphere (land surface) and biosphere, the Earth's cryosphere is considered to be one of the five spheres of the climate system. According to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) in 2007, the term "cryosphere" collectively describes components of the climate system consisting of all snow, ice, and frozen ground (including permafrost) on and beneath the surface of the earth and ocean. This includes solid precipitation, snow cover, ice sheets/shelves, permafrost, seasonally frozen ground, glaciers, ice caps, sea ice, and lake and river ice. Among the other countries in the world, China currently has the largest area of cryosphere distributed in mid-low latitude regions, which has significant effects on its climate, environment, water resources, and ecological processes. Components such as glaciers, frozen soil, and snow cover are widespread within China - particularly in the high-cold (high elevation and cold climate) regions, including the entire Tibetan Plateau as well as some high mountains in Gansu, Inner Mongolia, Xinjiang, and northeast China, which occupies the largest area of high-cold region in the world. Rapid changes in the components of the cryosphere have profound influences on the energy balance, atmospheric circulation, ocean circulation, water cycle, changes in sea level, sources and sinks of carbon, and socio-economic development, because it is highly sensitive to climate change and plays an important role in climate feedbacks.

Cryospheric research has attracted unprecedented attention in the context of global warming. Future cryospheric changes are considered to have wide and profound impacts on the ecological and environmental security and sustainable use of water resources in western China. In view of its importance, the Chinese government has provided sustained R&D funding in the field for decades. At present, the relevant research in China is still one of the most active fields in studies on global change, sustainable development and the climate system. As one of the early countries in the world conducting research in this area, China has made great progress in research on glaciers, snow cover, permafrost, polar ice caps, periglacial landforms, and regional climate thus far. Several leading domestic universities and research institutes represented by the Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI) of the Chinese Academy of Sciences (CAS) have achieved a high reputation worldwide for their comprehensive breakthroughs in the field. International peers have also been making positive comments regarding China's role in international research cooperation in cryospheric studies in recent years based on the country's active participation and major contributions to multiple joint international research projects such as the TiP Project, Dragoness Project, WCRP/CliC Project, TPE Project, etc. These collaborative projects entailed the study of water, soil, atmosphere, and biology and their interactions, as well as their influence on sustainable development in the cryospheric region. (More details can be found in section 2 below)

This report presents the current situation of cryospheric research in China, primarily including the relevant key national R&D programs, domestic leading research groups/organizations, and a short review of recent research advancements in the field. The research trends in China for this field are also discussed within.

**Note: This report uses a foreign currency conversion rate of 1 Chinese Yuan Renminbi (RMB) = .163 United States Dollar (US$).*

2. MAIN GOVERNMENT PROGRAMS

The Chinese government has been paying close attention to cryospheric research for some time. Sustained government R&D funding has been allocated in the field for several decades through most of the key national programs, such as the National Basic Research Program (973 Program) and the National Fundamental Investigation Projects (NFIP Program) of MOST and major programs by the NSFC and CAS, etc. Chinese researchers have also participated or are currently joining in numerous cooperative international research projects that are authoritative and influential in the field, e.g., the TiP Project (Sino-Germany cooperative project on geodynamics and environmental evolution on the Tibetan Plateau), the Dragoness Project (Sino-EU cooperative project on assessing and establishing an inventory of European and Chinese capacities in marine monitoring for environment and security, using satellite Earth observation technologies), the WCRP/CliC Project (an international cooperative project that aims to encourage and promote research into the cryosphere and its interactions as part of the global climate system) and the TPE Project (a joint study launched by China on the environment of the "Third Pole" region centered on the Tibetan Plateau and neighboring areas). All of these granted programs are playing an important role in the scientific accumulation of cryospheric research in China. Some representative programs in the field funded by Chinese government in the past decade are summarized in Tables 1 and 2 below.

Table 1. Main 973 Programs on Cryospheric Study (2005-2015)

Program Term	Program Title	Sub-program Titles	Funding (Sub-Program Allocation)	Chief Scientist (Principal Investigators of Sub-Program)	Affiliations
12/2005 - 11/2010	Environmental changes on Tibetan Plateau and their responses to global climate change and human adaptation	P1. Forming process of modern geomorphology and environment pattern on Tibetan Plateau	~ RMB 23.5 million in total (16% for P1; 17% for P2, P3 and 5; 19% for P4; 14% for P6)	Tandong YAO (P1. Xiaomin FANG; P2. Liping ZHU; P3. Ninglian WANG; P4. Tandong YAO; P5. Hua OUYANG; P6. Yili ZHANG)	The Institute of Tibetan Plateau Research (ITP), CAS (P1. P2. P4. ITP, CAS; P3. CAREERI, CAS; P5. P6. Institute of Geographic Sciences and Natural Resources Research (IGSNRR), CAS)
		P2. Temporal and spatial features of environment change on Tibetan Plateau in the past			
		P3. Cryospheric change and cycle process of energy and water on Tibetan Plateau			
		P4. Mechanisms of environment change on Tibetan Plateau			
		P5. Response of ecological system on Tibetan Plateau to environment change			

Program Term	Program Title	Sub-program Titles	Funding (Sub-Program Allocation)	Chief Scientist (Principal Investigators of Sub-Program)	Affiliations
		P6. Adaptation countermeasure study on the impact of Tibetan Plateau's environment change			
7/2007 – 10/2011	Cryospheric processes in China and their climatic, hydrologic, and ecologic effects and adaptation strategy	P1. Response mechanism study of different features/scales typical of glaciers to climate change	~RMB 31.7 million in total (15% for P1, and P2; 13% for P3 and P4; 12% for P5; 14% for P6; 17% for P7)	Dahe QIN (P1. Jiawen REN; P2. Baisheng YE; P3. Cunde XIAO; P4. Genxu WANG; P5. Bingyi WU; P6. Yongjian DING; P7. Dahe QIN)	CAREERI, CAS (P1. P2. P3. P6. P7. CAREERI, CAS; P5. Chinese Academy of Meteorological Sciences (AMS); 4. Institute of Mountain Hazards and Environment (IMHE), CAS)
		P2. Hydrological process simulation and water resource change projection in cryosphere region of typical basins in arid region			
		P3. Impact of glacier change in Himalaya Mountains to international rivers			
		P4. Frozen soil and snow cover change in the headwaters of the Yangtze and Yellow Rivers and their ecological effect			
		P5. Impact mechanisms of snow cover and frozen soil to China's climate change			
		P6. Temporal and spatial features of cryosphere change in past nearly 50 years and its future trend prediction			
		P7. Vulnerability assessment on cryosphere change and its adaptation countermeasure			

Program Term	Program Title	Sub-program Titles	Funding (Sub-Program Allocation)	Chief Scientist (Principal Investigators of Sub-Program)	Affiliations
9/2010 - 10/2014	Impacts of cryosphere in the northern hemisphere to climate and environment, and adaptation strategy	P1. Mechanism of glacier change in mountain land and its impact on the sensitivity and hydrological effect of climate change P2. Response mechanism of frozen soil to climate change and its carbon cycle process P3. Change of sea ice and snow cover and its impact on climate P4. Comprehensive climate and environment effects of cryosphere change and adaptation countermeasure	~RMB 27.4 million in total	Ninglian WANG (P1. Shichang KANG; P2. Qingbai WU; P3. Fei HUANG; P4. Ninglian WANG)	CAREERI, CAS (P1. ITP, CAS; P2. CAREERI, CAS; P3. Ocean University of China; P4. CAREERI, CAS)
9/2010 - 10/2014	Changes of Tibetan regional climate system and its impacts to East Asia	P1. Research on relationship between the reciprocity of earth and atmosphere on Tibetan Plateau and the anomalies of atmospheric circulations P2. Research on response of multi-layer interactive processes on Tibetan Plateau to climate change P3. Impact and mechanisms of Tibetan Plateau's climate system to the climate change in East Asian	~RMB 32.7 million in total	Yaoming MA (P1. Yaoming MA; P2. Lide TIAN; P3. Anmin DUAN; P4. Yili ZHANG)	ITP, CAS (P1. P2. ITP, CAS; P3. Institute of Atmospheric Physics (IAP), CAS; P4. IGSNRR, CAS)

Program Term	Program Title	Sub-program Titles	Funding (Sub-Program Allocation)	Chief Scientist (Principal Investigators of Sub-Program)	Affiliations
		P4. Research on response of ecological and socioeconomic system on Tibetan Plateau to climate change and its adaptation countermeasure			
7/2013 - 2017	Changes of global cryosphere and their impacts	P1. Processes modeling of mountain glacier changes	~RMB 27.4 million for the first two years; N/A for the last three years	Yongjian DING (P1. Jiawen REN; P2. Tingjun ZHANG; P3. Lin ZHAO; P4. Cunde XIAO; P5. Yanluan LIN; P6. Rensheng CHEN; P7. Genxu WANG; P8. Yongjian DING)	CAREERI, CAS (P1. P3. P4. P6. P8. CAREERI, CAS; P2. Lanzhou University; P5. Tsinghua University; P7. IMHE, CAS)
		P2. Snow cover data retrieval over complex topography areas			
		P3. Moisture/energy processes in frozen ground areas and climatic responses			
		P4. Key processes of polar cryosphere and responses to global climate change			
		P5. Components-integrated coupling of cryosphere into climate models			
		P6. Cold regions hydrological stimulation and prediction			
		P7. Impacts of cryospheric changes to ecosystem and carbon cycles			
		P8. Comprehensive analysis of cryosphere change impacts and its adaptation mechanisms			

Program Term	Program Title	Sub-program Titles	Funding (Sub-Program Allocation)	Chief Scientist (Principal Investigators of Sub-Program)	Affiliations
2015-2019	Arctic amplification mechanism induced by reduction of polar sea ice and its global climate effect	N/A	~RMB 12.3 million for the first two years; N/A for the last three years	Jinping ZHAO	Ocean University of China
2015-2019	Changes of meridional circulation in Antarctic circumpolar current region in the context of global warming and its climate effect	N/A	~RMB 2.5 million for the first two years; N/A for the last three years	Yu ZHANG	Ocean University of China

Table 2. Main NFIP* Programs and programs of NSFC on cryospheric study (2005-2015)

Program Term	Program Title	Funding (RMB million)	Chief Scientist	Affiliations	Funding Sources and Types
2007-2012	2nd investigation on China's glacier inventory and change	22.3	Shiyin LIU	CAREERI, CAS	MOST's NFIP Program
1/2009 – 12/2013	Permafrost investigation on Tibetan Plateau	15	Lin ZHAO	CAREERI, CAS	MOST's NFIP Program
1/2009 - 12/2012	Observation of reciprocity of earth and atmosphere on Tibetan Plateau and satellite remote sensing application	2	Yaoming MA	ITP, CAS	NSFC's National Science Fund for Distinguished Young Scholars
1/2011 - 12/2014	Research on balance model of mass and energy of distributed glacier	~2.5	Tianding HAN	CAREERI, CAS	NSFC's Key Program
1/2012 - 12/2016	Expeditions over data-scarce areas on Tibetan Plateau	N/A	Liping ZHU	ITP, CAS	MOST's NFIP Program
1/2012 - 12/2014	Research on cryosphere and global change	6	Dahe QIN	IGSNRR, CAS	NSFC's National Science Fund for Distinguished Young Scholars
1/2012 - 12/2016	Phases transition of water bodies over the third Pole and impacts	20	Tandong YAO	ITP, CAS	NSFC's Major Program
1/2013 - 12/2016	Research on geography in cryosphere region	2	Shichang KANG	ITP, CAS	NSFC's National Science Fund for Distinguished Young Scholars

1/2013 - 12/2016	Research on coupling mechanism and model of eco-hydrological process on upstream of Heihe river basin	~10.8	Dawen YANG	Tsinghua University	NSFC's Major Research Plan
1/2013 - 12/2017	Research on coupling mechanism and process of cycles and tectonic uplift during Quaternary glacial period on the Tibetan Plateau	3.5	Zhijiu CUI	Peking University	NSFC's Key Program
1/2014 - 12/2017	Research on process of surface water and underground water in the frozen soil region of Heihe river upstream	3	Tingjun ZHANG	Lanzhou University	NSFC's Major Research Plan
1/2014 - 12/2018	Ice core record from Chongce ice cap of West Kunlun Mountain since the last interglacial period and impact of glacier change to climate	3	Shugui HOU	Nanjing University	NSFC's Key Program

Notes:

**The NFIP Program by MOST mainly supports important scientific fundamental work that lacks steady funding channels such as scientific observation and investigation, comprehensive and in-depth collection and treatment of scientific data and materials, establishment, the maintenance and update of scientific standards and standard substances, etc.*

Acronyms: CAS = Chinese Academy of Sciences; ITP = Institute of Tibetan Plateau Research; IGSNRR = Institute of Geographical Sciences and Natural Resources Research (IGSNRR); MOST = Ministry of Science and Technology; NFIP = National Fundamental Investigation Projects; NSFC = National Natural Science Foundation of China

3. LEADING RESEARCH ORGANIZATIONS

Cryospheric science is the interdisciplinary study of permafrost, snow, and ice, with techniques from geophysics, meteorology, and hydrology, so in China a number of research organizations involved in the fields of earth and environmental sciences are presently conducting relevant studies. Many CAS institutes, such as CAREERI, ITP, IGSNRR, IAP, and IMHE, etc., are very active in the field, with a relatively long research history, strong scientific strength, high-end talents, and adequate R&D funding for cold region climate and environment research in China. At the present time, most of the relevant top Chinese journals, such as *Journal of Glaciology and Geocryology*, *Sciences in Cold and Arid Regions*, and *Plateau Meterology*, etc., are founded by those CAS institutes and also contribute most of China's publications relevant to the field in top international journals such as *Nature*, *Scientific Reports*, and *Climate Dynamics*, etc. Other domestic universities leading in the field are mainly concentrated in the cold region of China, including the comprehensive universities represented by Lanzhou University, Jilin University, Heilongjiang University, etc. as well as special discipline-based universities represented by Northeast Forestry University, Shenyang Agricultural University, and the Ocean University of China, etc. In addition to CAS institutes, there are also some other professional research institutes as the leading players in the field, e.g., AMS, the Polar Research Institute of China, Heilongjiang Hydraulic Research Institute, etc. For the sake of brevity, the following sections focus on introducing only two representative CAS institutes: CAREERI and ITP, both of which have achieved a high reputation worldwide for their comprehensive breakthroughs in the field of cryospheric research.

3.1 Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI)

Located at Lanzhou City in the Northwest of China, CAREERI was established in 1999 upon the merger of the former CAS Lanzhou Institute of Glaciology and Geocryology, the Lanzhou Institute of Desert Research, and the Lanzhou Institute of Plateau Atmospheric Physics. Focusing on the terrestrial processes of cold and arid regions as well as their interactions at various spatiotemporal scales and impacts on the global/regional climate and environment, CAREERI has established seven research divisions: 1) Remote Sensing and Geographic Information System Laboratory; 2) Ecology and Agriculture Laboratory; 3) Water and Land Resources and Environments Laboratory, 4) Plateau Atmospheric Physics Research Laboratory, 5) Desert and Desertification Laboratory, 6) Frozen Soil Engineering Laboratory, and 7) Cryospheric Sciences Laboratory – of which the last two are State Key Laboratories. The institute also presently has an experiment and observation research platform consisting of 16 field stations. The total staff of CAREERI currently numbers more than 600, and among whom more than 100 are researchers and associate researchers - including three academicians of CAS. Table 3 presents the leading groups engaged in relevant research at CAREERI.

Table 3. Leading Research Groups on Cryospheric Study at CAREERI

Leading Researcher	Interests	Title/Position
Dahe QIN	Physical geography (Cryosphere and environment)	Academician of CAS and of the Third World Academy of Sciences; former Administrator of the China Meteorological Administration (CMA) and former Permanent Representative of China with the World Meteorological Organization (WMO); founder of the State Key Laboratory on Cryospheric Science (SKLCS)
Jiawen REN	Glaciology	Executive vice-director of SKLCS
Shichang KANG	Physical geography	Director of SKLCS
Ninglian WANG	1. Climatic and environmental records in ice cores; 2. Glaciers, water resources and global change; 3. Solar activity and the Earth climate change; 4. Teleconnection between climatic changes in different areas	Deputy director of CAREERI
Cunde XIAO	1. Physics of glaciers; 2. Glacier and climate change	Executive vice director of SKLCS; deputy chairman of International Association of Cryospheric Sciences (IACS)
Yongjian DING	1. Glaciers and cold regions environment; 2. Hydrology and water resources; 3. Hydrogeology and engineering geology	Deputy director of CAREERI
Shiyin LIU	1. Glaciology; 2. Glacial hydrology and glacial hazards; 3. Remote sensing of snow and ice	Member of International Glaciological Society (IGS)
Lin ZHAO	Geocryology	Director of cryosphere research station on Tibetan Plateau
Qingbai WU	1. Frozen soil environment and global change; 2. Interaction between frozen soil and environment in cold regions; 3. Gas hydrates in permafrost regions	Executive vice director of the State Key Laboratory of Frozen Soil Engineering

3.2 Institute of Tibetan Plateau Research (ITP)

Founded in 2003, ITP is engaged in the study of climate and environmental changes on the Tibetan Plateau and their impact. The institute presently has three campuses in Lhasa, Beijing and Kunming, respectively. The main function of the Beijing campus is to establish a high-level experimental laboratory to conduct indoor research. The main function of the Lhasa campus is to implement field experiments and observations; it operates the Tibetan Observation and Research Platform (TORP), which currently comprises five constructed field stations on the Tibetan Plateau. The Kunming campus is to primarily carry out life process research under the extreme environment. The institute currently consists of three laboratories. The CAS Key Laboratory of Tibetan Environment Changes and Land Surface Processes (TEL) focuses on environmental changes on the Tibetan Plateau, and their impact on and response to global change and human adaptation. The current director of TEL is Prof. Tandong YAO, a Chinese academician who was awarded the earth sciences prize of the Holeung Ho Lee Foundation. The CAS Key Laboratory of Continental Collision and Plateau Uplift (LCPU) focuses on the collision of the Indian-Eurasian plates and the associated uplift processes and mechanisms for the Tibetan Plateau. The CAS Laboratory of Alpine-Cold Ecology and Biodiversity focuses on the responses of alpine ecosystems to global change, as well as biodiversity features and formation mechanisms under extreme environmental conditions. ITP is becoming an acknowledged international research center in cryospheric study through multiple international cooperative programs such as TiP, and TPE, etc. Table 4 presents the leading groups engaged in relevant research at ITP.

Table 4. Leading Research Groups Engaged In Cryospheric Research at ITP

Leading Researcher	Interests	Title/Position
Tandong YAO	Glacier environment and global change	Academician of CAS; Director of ITP and TEL
Xiaomin FANG	Uplift of Tibetan Plateau and environmental change	Assistant to the director of ITP
Liping ZHU	Global change and quaternary environment	Secretary general of China Society on the Tibetan Plateau
Yaoming MA	Atmospheric boundary layer observation	Deputy director of ITP; Director of the CAS Qomolangma Station for Atmospheric and Environmental Observation and Research
Lide TIAN	Glaciers and cold region environments	Member of IGS

4. RESEARCH ADVANCEMENTS

Research on the cryosphere in China began in the late 1950s. With decades of strong efforts, Chinese researchers have made fruitful achievements in the scientific study of cryospheric changes. Recent advances focus on an understanding of how the snow cover over the Tibetan Plateau and Eurasia, permafrost, and glaciers influence the atmospheric circulation over East Asia as well as the impacts on climate and environment in China. A brief overview of the important research advancements made in recent years is presented in the sections below.

4.1 Cryospheric Change and Impacts

As mentioned earlier, China is one of most cryosphere-developed countries in the mid-low latitude region. Main components of the cryosphere, such as glaciers, frozen soil, and snow cover are widespread within China (see Figure 1 below). The global cryosphere has undergone significant changes in recent decades. Nearly all of the elements of the cryosphere have lost mass as a result of global warming. Cryospheric changes in China are largely consistent with changes in the global cryosphere.

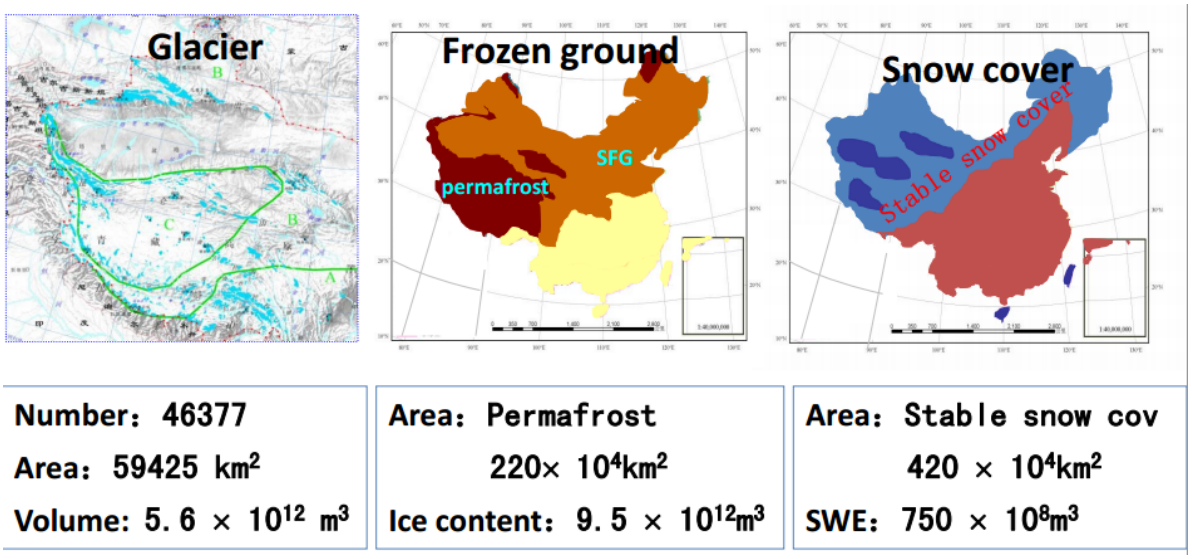

Figure 1. Distribution of main components of the cryosphere in China, with specific mapping data

Most of the glaciers in China have receded under global warming. According to Prof. Dahe QIN's report, approximately 82% of Chinese glaciers have receded or disappeared since the 1960s, resulting in the loss of more than 10% of the glacier area. Glacier recession has accelerated since the 1990s.

Permafrost on the Tibetan Plateau has undergone significant changes over the past two decades. On one hand, permafrost temperatures have warmed substantially. Chinese researchers reported that the temperature of permafrost areas in the low and middle mountain ranges of the Tibetan Plateau has increased from about -3°C to up to 1°C, while the temperature of permafrost in river valleys and basins has reached values between -1 and 0.5°C. The temperature of upper-layer permafrost has increased at a rate of 0.1°C per year. On the other hand, a substantial amount of permafrost has experienced direct degradation. Permafrost with temperatures lower than -3°C has no severe degradation. By contrast, many permafrost areas with temperatures higher than -1°C have receded. Chinese researchers also found that the thickness of seasonally frozen ground has also decreased. The maximum depth of seasonally frozen ground on the Tibetan Plateau thinned at an average rate of 3.3 mm per year between 1961 and 2006.

The depth of snow cover over the Tibetan Plateau increased steadily over the latter half of the 20th century, but decreased significantly during the early part of the 21st Century. According to Prof. QIN, the maximum snow depth in northern Xinjiang has increased at an average rate of 0.8% since 1961. The depth of snow cover in Northeast China-Inner Mongolia shows no obvious long-term trends, but the amplitude of interannual fluctuations has increased substantially since the 1990s.

Based on the results of many Chinese researchers in the field, the Chinese cryosphere is projected to continue to decrease in both area and volume during the following decades. Smaller glaciers and glaciers that contact the ocean are projected to recede significantly. The thickness of the active layer of permafrost is expected to continue increasing, while the area and thickness of seasonally frozen ground are expected to continue decreasing. Changes in snow cover are projected to vary substantially among different cold regions.

4.2 Climate and Environment Response

4.2.1 Snow Cover

Chinese scientists have carried out a number of studies examining how snow cover over the Tibetan Plateau impacts precipitation and the East Asian summer monsoon. Despite isolated discrepancies due to differences in snow cover data or analysis periods, most studies show negative correlations between winter-spring snow cover over the Tibetan Plateau and the East Asian summer monsoon. The most significant climatic effect of snow cover over the Tibetan Plateau is its influence on summer precipitation in China. According to Chinese researchers' results winter-spring snow cover over the plateau is positively correlated with summer (June-August) precipitation in the Yangtze River valley and negatively correlated with summer precipitation in South China and North China. Moreover, winter-spring snow cover over the plateau is positively correlated with early summer (May-June) precipitation in South China and negatively correlated with early summer precipitation over the Yangtze River valley. Furthermore, interdecadal variations in winter-spring snow cover over the plateau are associated with changes in the spatial pattern of summer precipitation in Eastern China. Chinese researchers have also examined the impacts of Eurasian snow cover on Chinese climate. Their studies show that interannual variations in winter-spring Eurasian snow cover are in phase with summer precipitation in Northeast China and Southwest China and out of phase with summer precipitation in the Yangtze-Huaihe River valley. Changes in Eurasian snow cover also significantly influence springtime precipitation over China. Chinese researchers think the significant decreases in springtime Eurasian snow cover since the 1980s are an important reason for the simultaneous decreases in precipitation over Southeastern China and increases in precipitation over Southwestern China.

4.2.2 Permafrost

Chinese researchers have demonstrated that the Tibetan Plateau permafrost plays an important role in surface heat flux changes. The freezing and thawing of plateau soils can enhance the exchange of heat between the land and atmosphere, and significantly influence atmospheric circulation patterns (including the South Asian high, the western Pacific subtropical high, and the Indian low). Hydrothermal changes resulting from freeze-thaw processes over the Tibetan Plateau appear to have important influences on East Asian climate with significant implications for precipitation in eastern China (particularly during the flood season). Chinese researchers also showed that the thaw date over the plateau is positively correlated with summer precipitation over the mid-lower reaches of the Yangtze River valley. In addition, several studies have investigated the influence of freeze-thaw processes in the Tibetan Plateau permafrost on atmospheric circulation and regional climate of East Asia via permafrost simulations based on land-atmosphere coupled models.

4.2.3 Glacier

Chinese researchers have reported that glacial melt water can have a significant impact on river runoff if the glacier coverage in the basin exceeds 5%. Their studies showed that approximately 70% of the increase in runoff in the headwaters of the Urumqi River in recent years has been supplied by increases in glacial melt. About one third of the increase in runoff in Aksu, Xinjiang can be attributed to increases in glacier runoff. Glacier melt water in the basin above Zhimenda hydrological station in the headwaters of the Yangtze River has increased by 15% over the past 40 years, even as river runoff has decreased by 14%. Some researchers think these increases in river flow due to glacial melt are beneficial at present, but it is worth noting that the associated loss of glacier mass will eventually result in rapid decreases in river runoff.

4.2.4 Vegetation

Chinese researchers modified a coupled biogeography and biogeochemistry model (BIOME4) to simulate the responses of biome distribution to future climate change in China. The simulation results suggest that regional climate change would result in dramatic changes in vegetation distribution in China. For example on the Tibetan Plateau the area of forests increased by spreading into the interior of the plateau, whereas tundra and dry tundra retreated towards the northwest. The desert in northwest China may be reduced and replaced by grassland and dry shrubland because of increased precipitation.

5. RESEARCH TRENDS

In 2013, MOST issued a national mid-/long- term scientific research plan in the field, aiming to guide the relevant research in the future. General targets of the plan in the long run include: (1) improving the general climate model (GCM) containing refined cryospheric components; (2) proposing the strategic measures for adaption of cryospheric change; and (3) developing the system of cryosphere sciences. In addition to the general targets in the plan, more specific targets in terms of different research aspects are also proposed (see Figure 2 below).

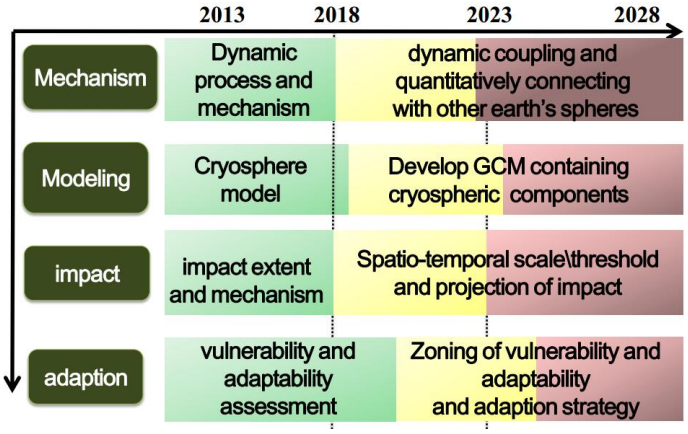

Figure 2. Specific long-term targets of cryospheric research in China

Moreover, Profs. Yongjian DING and Cunde XIAO at CAREERI both think the research basis of the field in China still remains relatively weak, and to further strengthen it for the near future Chinese researchers should put more effort in the following: (1) obtain global monitoring data

through extensive international cooperation, (2) obtain spatial distribution by virtue of multi-source remote sensing information, and (3) obtain precise data used for mechanism research through typical measurements.

6. CONCLUSION

The effects of cryospheric change in China have become increasingly distinct under global warming, with significant impacts on regional climate, water resources, ecology, environment, and sustainable development. The regions directly affected by the cryosphere in China are both ecologically vulnerable and economically underdeveloped. Therefore, China's cryospheric research is not only of scientific importance, but also demonstrates the urgency to meet the needs of national strategic requirements. In view of this, sustainable financial supports have been provided by the government in the field for decades. Significant achievements have been made in the research of cryospheric change through continuous investigation of glacier inventories, frozen ground observations, paleo-climate analyses of ice cores, process studies and the modeling of cryopsheric/atmospheric interactions. However, the research basis of the field still remains relatively weak, and the examination of possible strategies for adapting to the impacts of cryospheric change is still in its infancy in China and needs to be strengthened in the future.

END OF REPORT